First performance results for the LHCb Silicon Tracker

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Abstract: The LHCb detector is a single arm forward spectrometer designed to study the decays of B-mesons in proton-proton collisions at the Large Hadron Collider (LHC). The LHCb Silicon Tracker (ST) is a silicon micro-strip detector with a sensitive area of 12 m2 and a total of 272 thousand readout channels. The detector, which was fully installed by early summer 2008, currently has more than 99% of channels fully functioning. We present the results of calibration and performance studies of the ST using data collected by the experiment during LHC proton-proton collisions in late 2009 and spring 2010.

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Universität Zürich

First performance results for the LHCb Silicon Tracker

12th topical seminar on Innovative Particle and Radiation Detectors

Siena, 7th June 2010

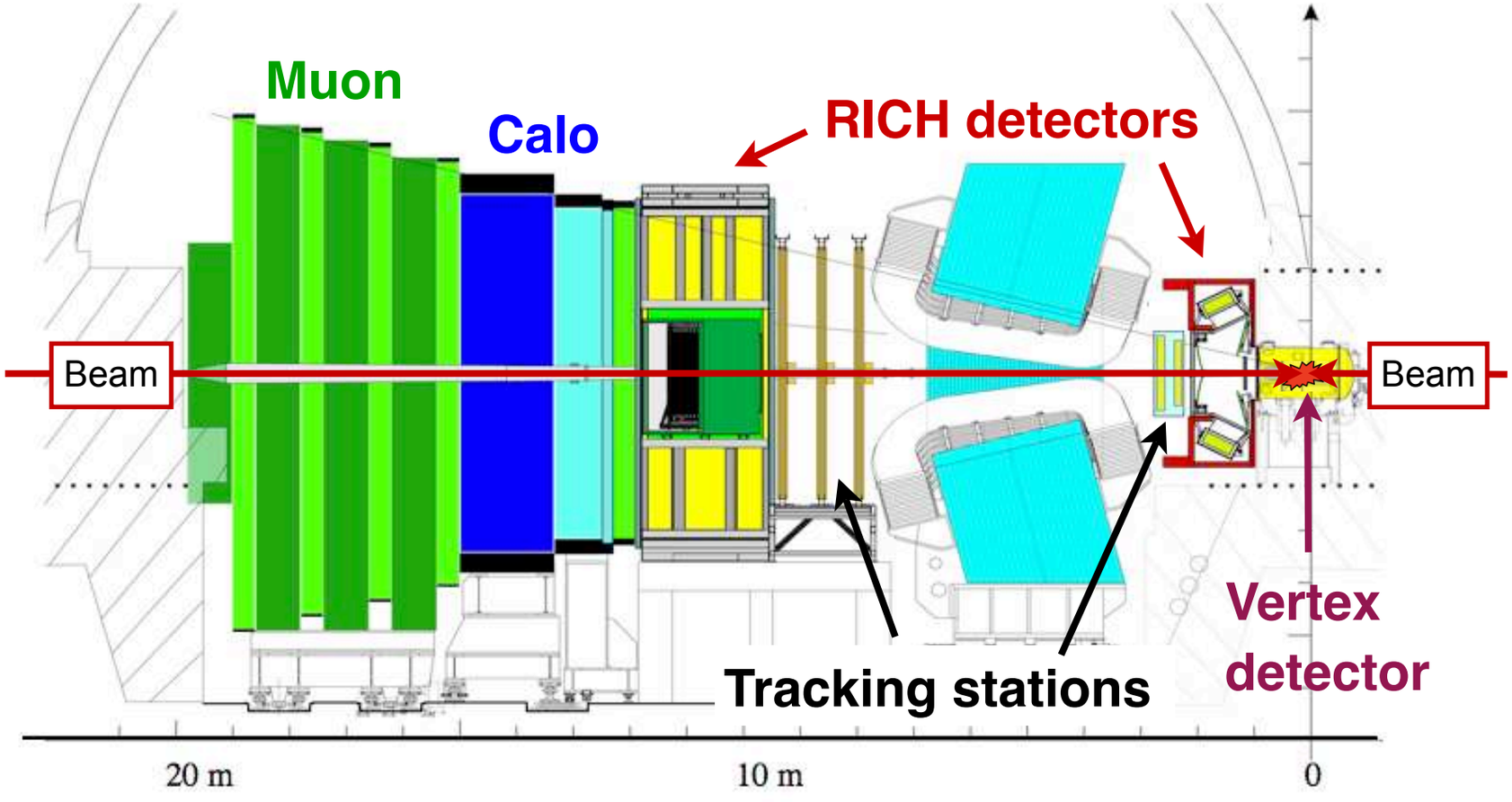
Jonathan Anderson

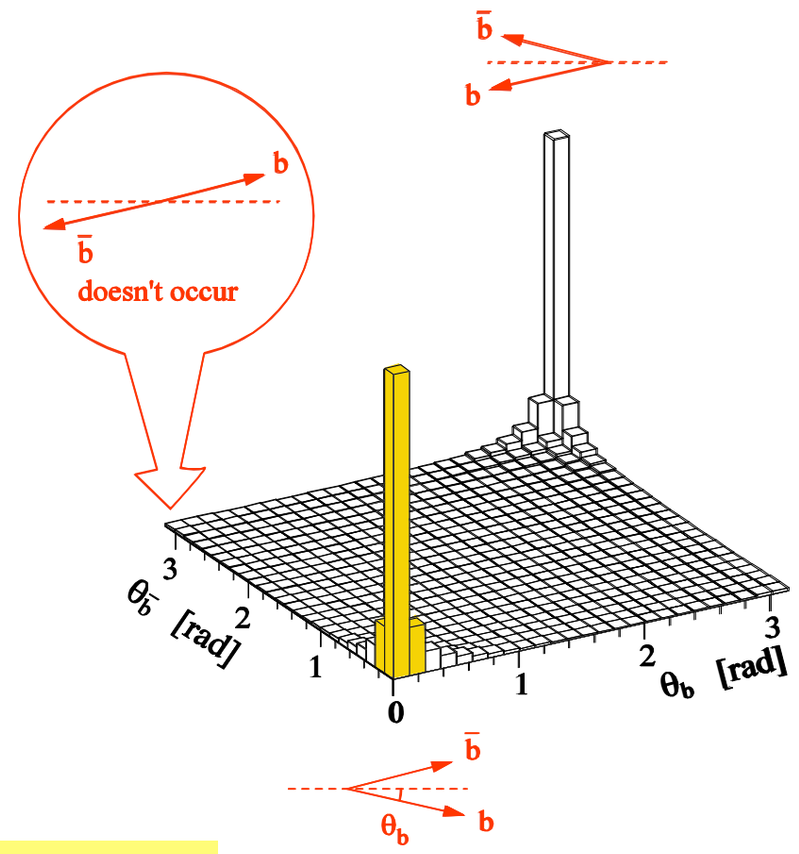
On behalf of the LHCb Silicon Tracker group

LHCb: A forward spectrometer

Dedicated b-physics experiment at the LHC

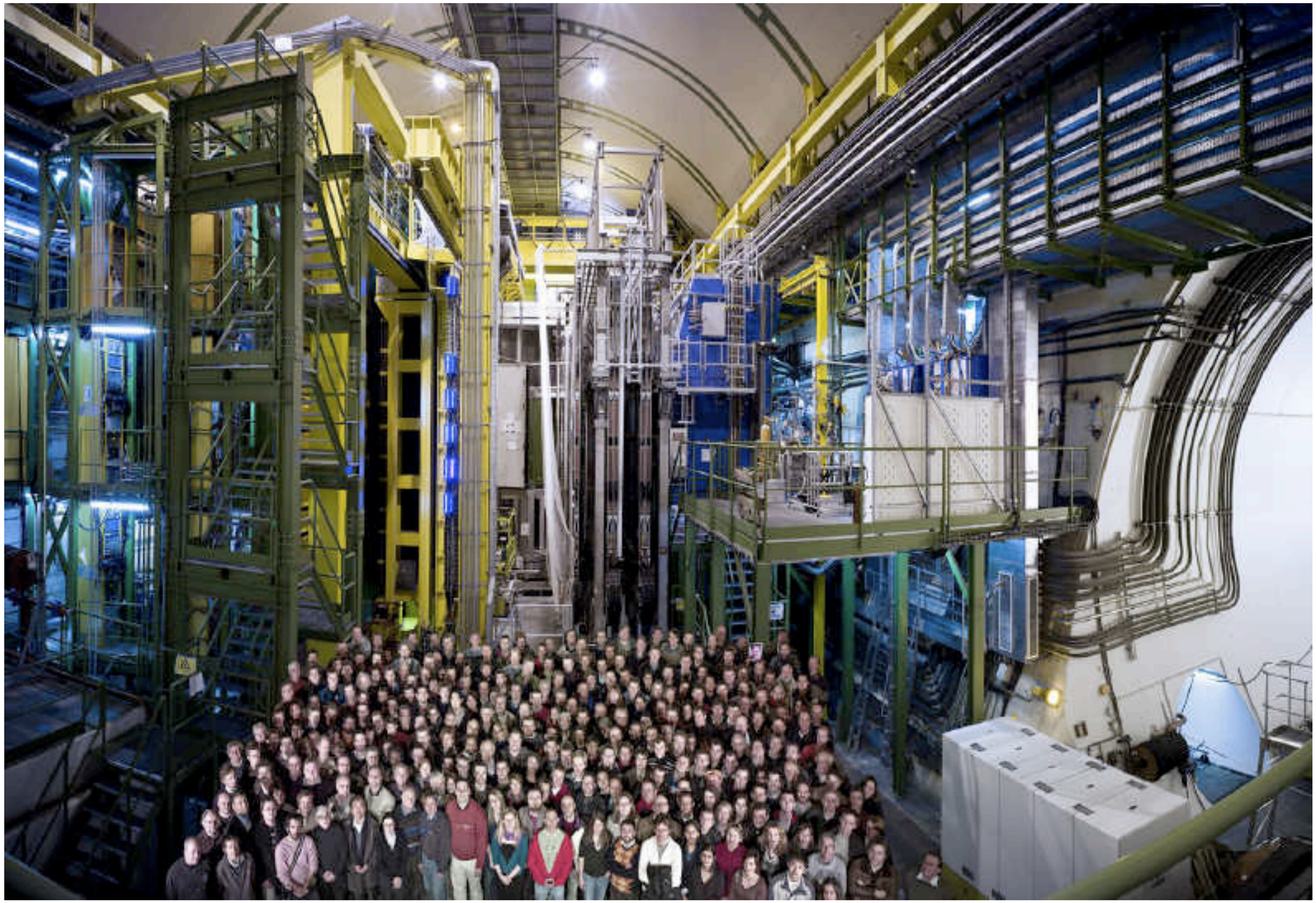
- Exploit copious b production at LHC to study CKM parameters and search for New Physics
- In p-p collisions at the LHC bb pairs are mostly produced in the same forward/backward cone
- 4pi detector not optimal: Instrumented in the forward region (1.9 < n < 4.9)





See the following talks for more:
R. Lindner (LHCb detector and first resullts), S. Eisenhardt (RICH), O. Deschamps (CALO), G. McGregor (VELO), A. Perez-Calero Yzquierdo (Trigger)

LHCb: A forward spectrometer



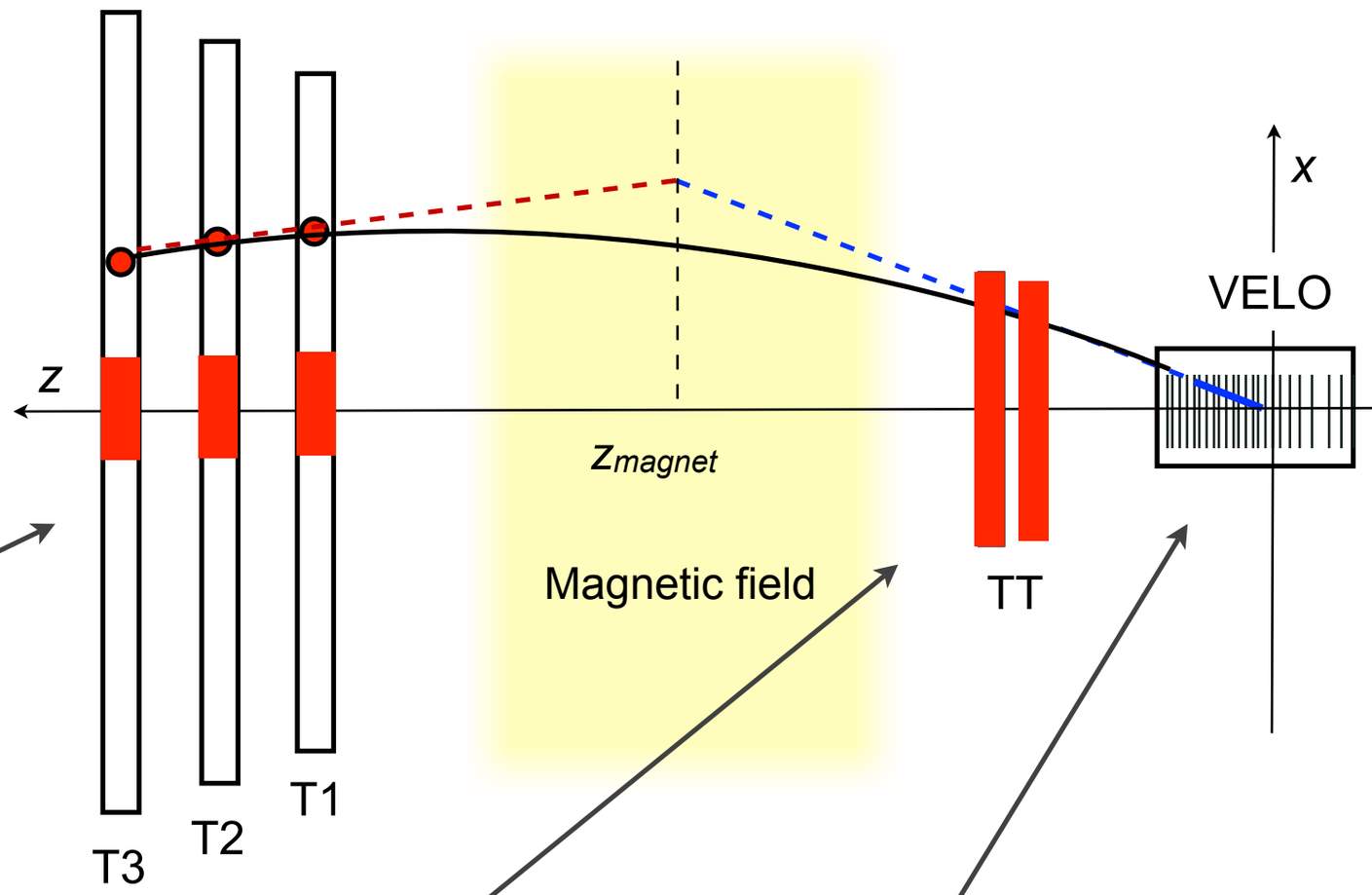
Fully installed, commissioned and taking data - O($10nb^{-1}$) of data on tape!
Increasing rapidly - $1fb^{-1}$ expected by end 2011
(note: LHC will run at $\sqrt{s}$ = 7 TeV during 2010/2011 run)

The LHCb tracking system

Threefold purpose:

- Track slopes before and after magnet give particle momentum
- Reconstruct vertices
- Extrapolate tracks to RICH, CALO and Muon: Particle ID

B-field in y-dir: Charged particles deflected in x-dir



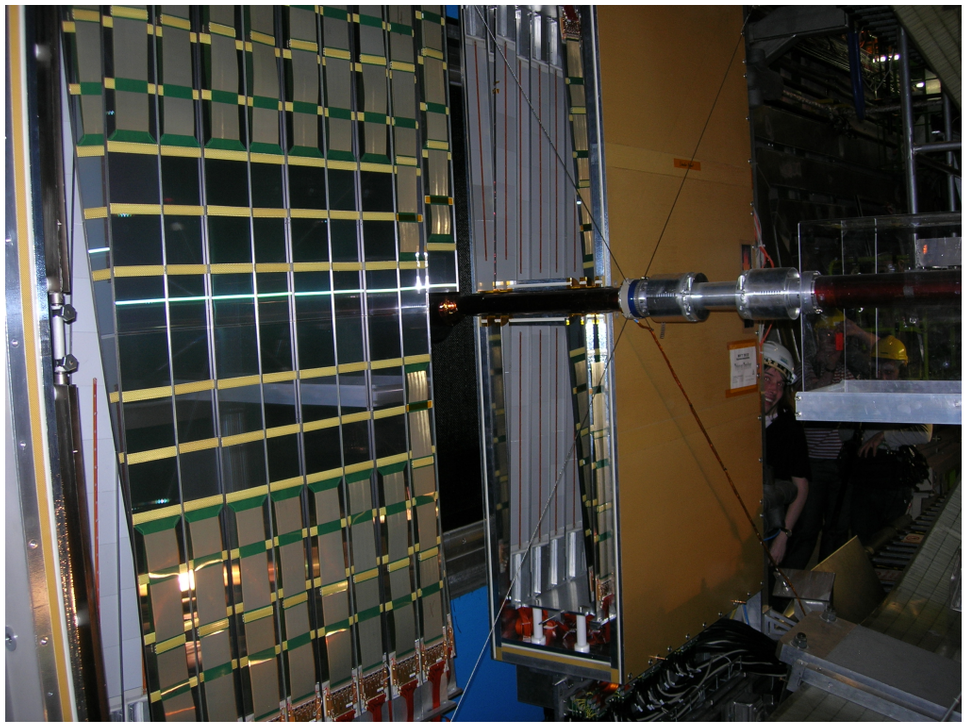
T-stations
- Outer Tracker (straw tubes)
- **Inner Tracker (IT)**: silicon strips (Flux highest in inner region)

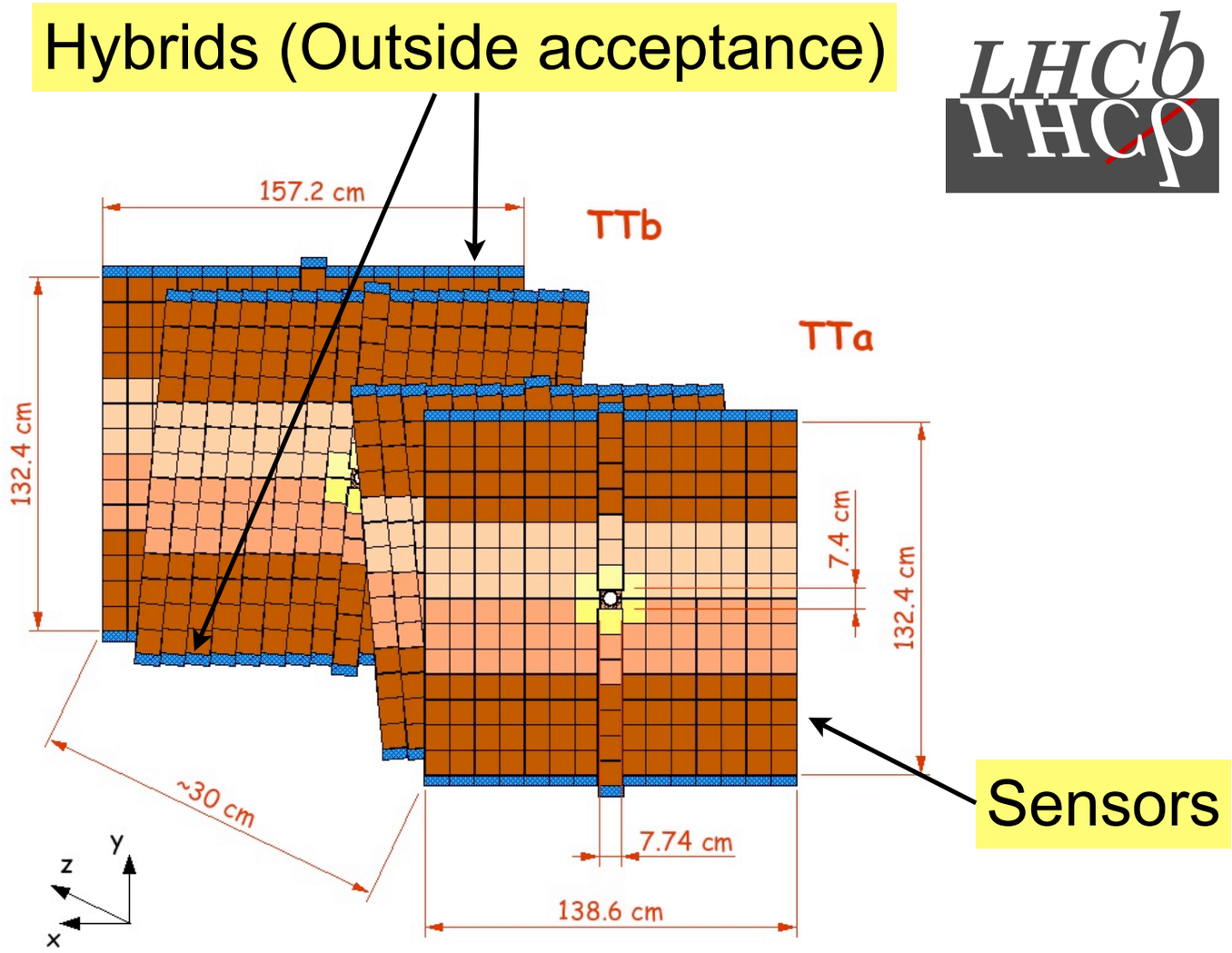
Tracker Turicencis (TT)
- Full coverage
- Silicon strips

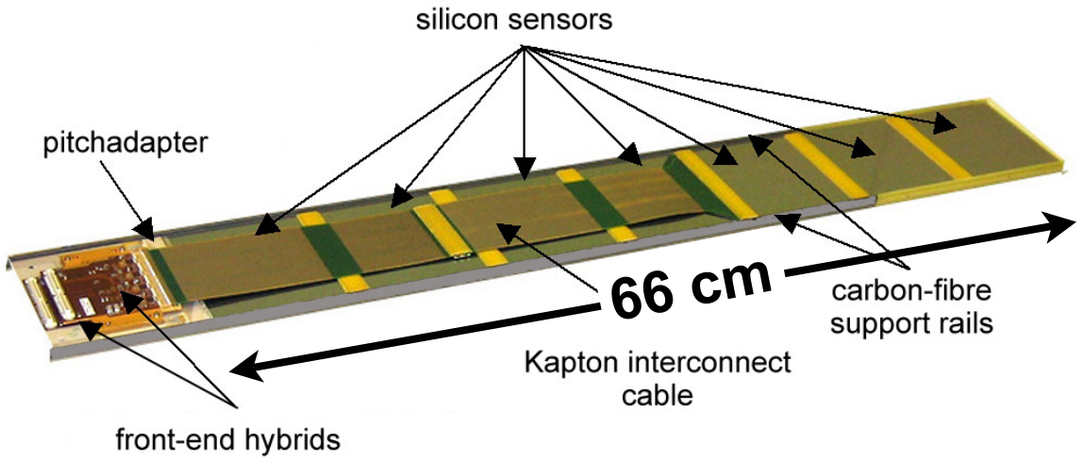
Vertex detector
- Silicon strips
- see G. McGregor talk

TT + IT developed in common project - LHCb Silicon Tracker group (35 physicists)

Tracker Turicensis

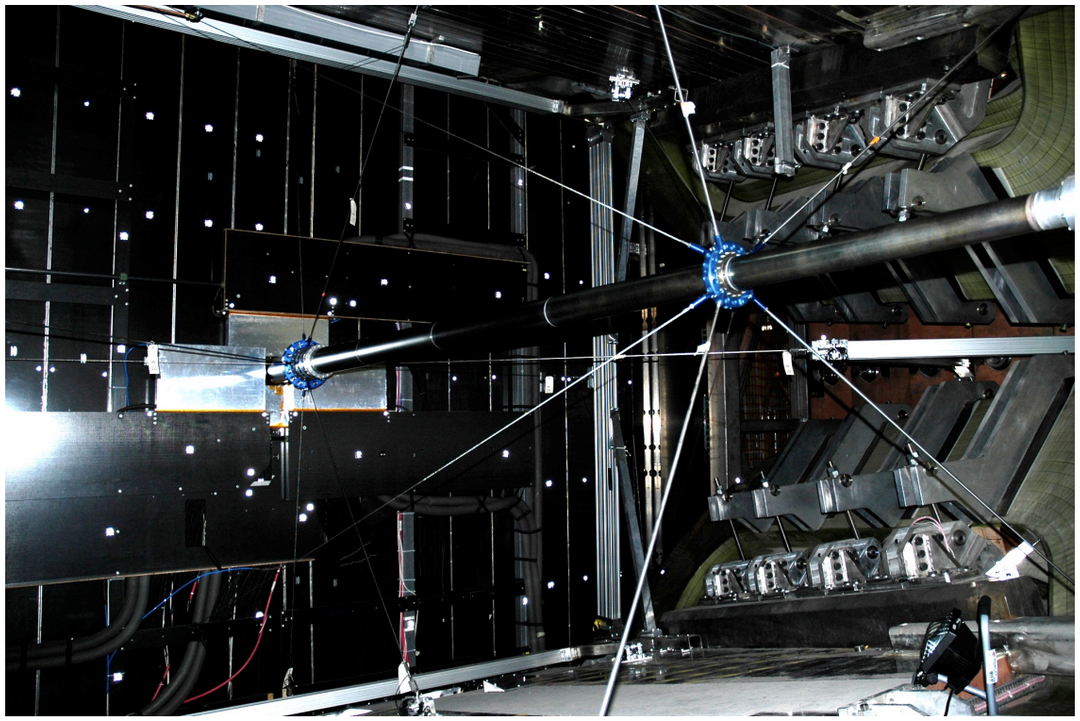


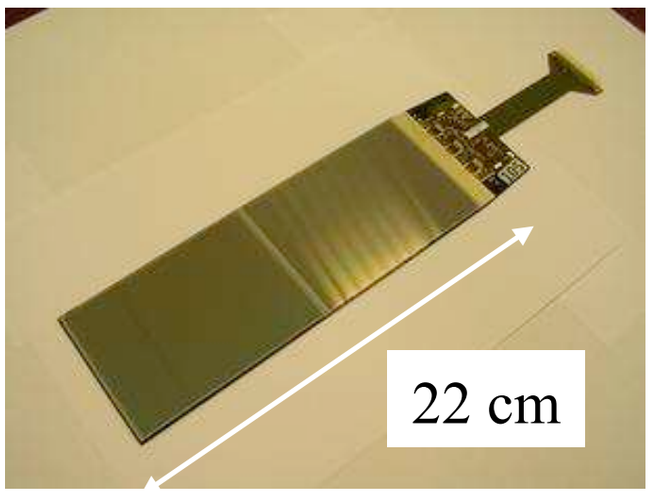


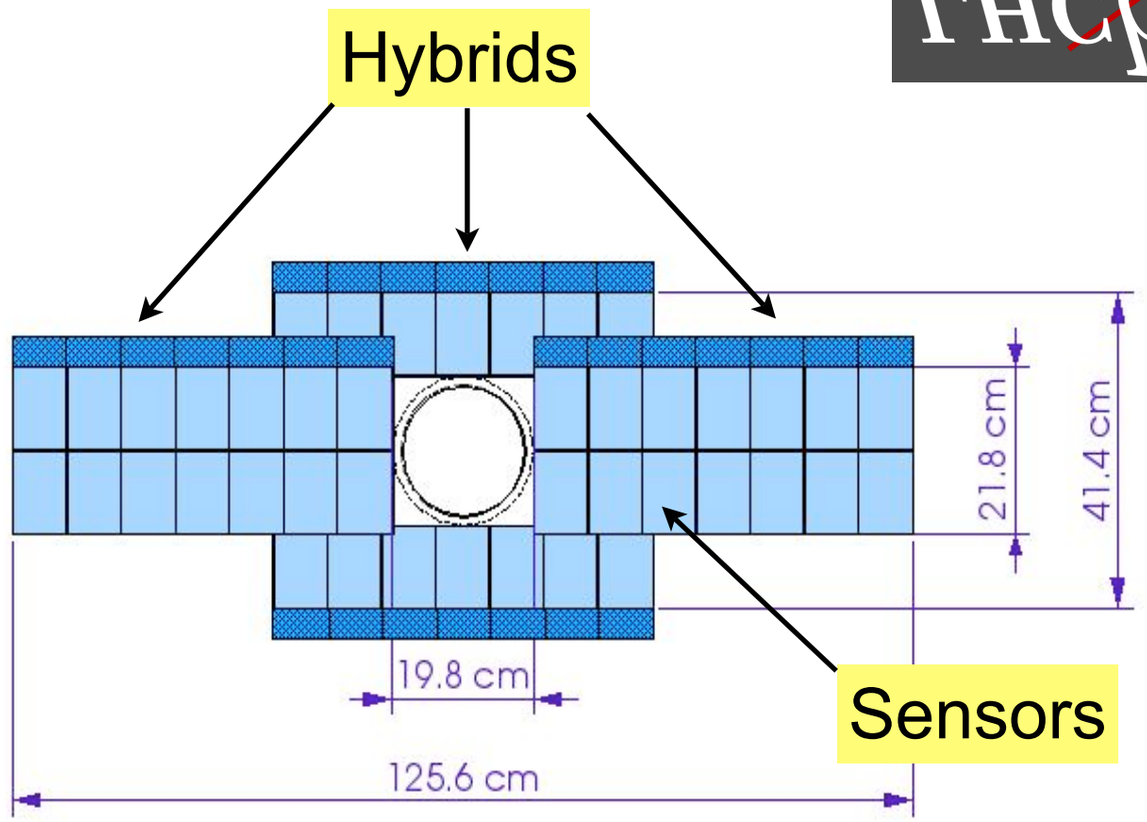


- Four planes of silicon (0°, +5°, -5°, 0°)
- 500μm thick, 183μm pitch
- Long strips (up to 37cm), Capacitance 56 pF (1, 2, 3 or 4 sensor readout sectors)
- Total area 8.2m2, 143k strips
- Total station 7% radiation length
- Detector operated at 5°C
- Front end on detector, digitization in off-detector service box (outside acceptance)

Inner Tracker





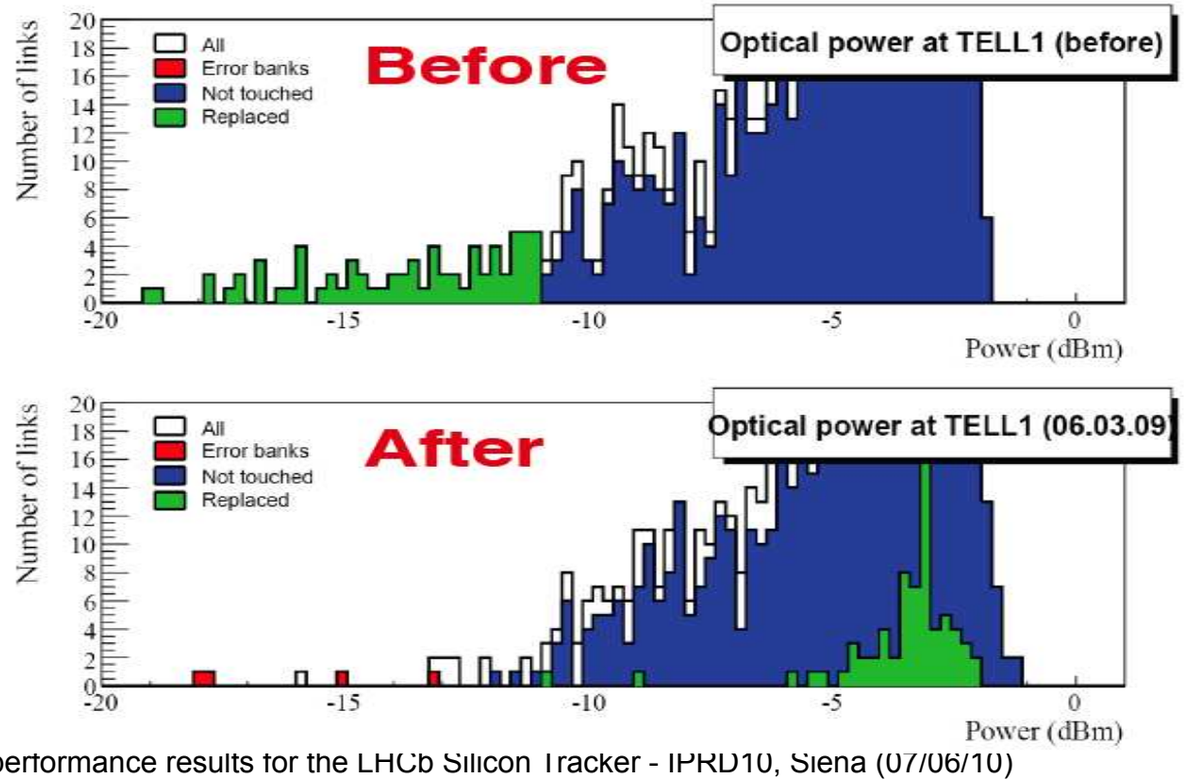


- Four planes of silicon per box (0˚, +5˚, -5˚, 0˚)
- 320 μm or 410 μm thick, 198 μm pitch
- Strips either 11 cm or 22 cm long
  (1 or 2 sensor readout sectors)
- Total area 4 m^2, 130k strips
- 3 stations: 4% radiation length each
- Detector operated at 5˚C
- Front end on detector, digitization in
  off-detector service box (outside acceptance)

Commissioning before collisions

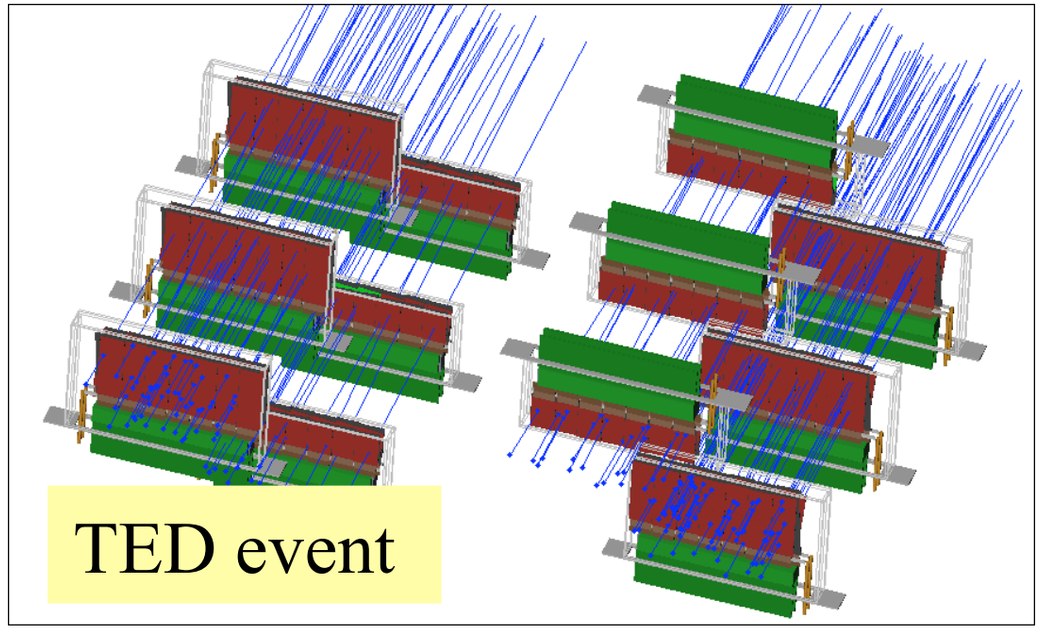
Commissioning without particles

- Regular standalone and global-LHCb runs
- High rate (1MHz) tests
- Many problems discovered and fixed
  - Oscillations in LV (fixed with capacitors)
  - Failing voltage regulators (30/1992 replaced)
  - Low power in optical readout VCSELs
    (damaged during mounting - 6% replaced)
  - Find cable swaps, bad connections etc.



Commissioning with particles

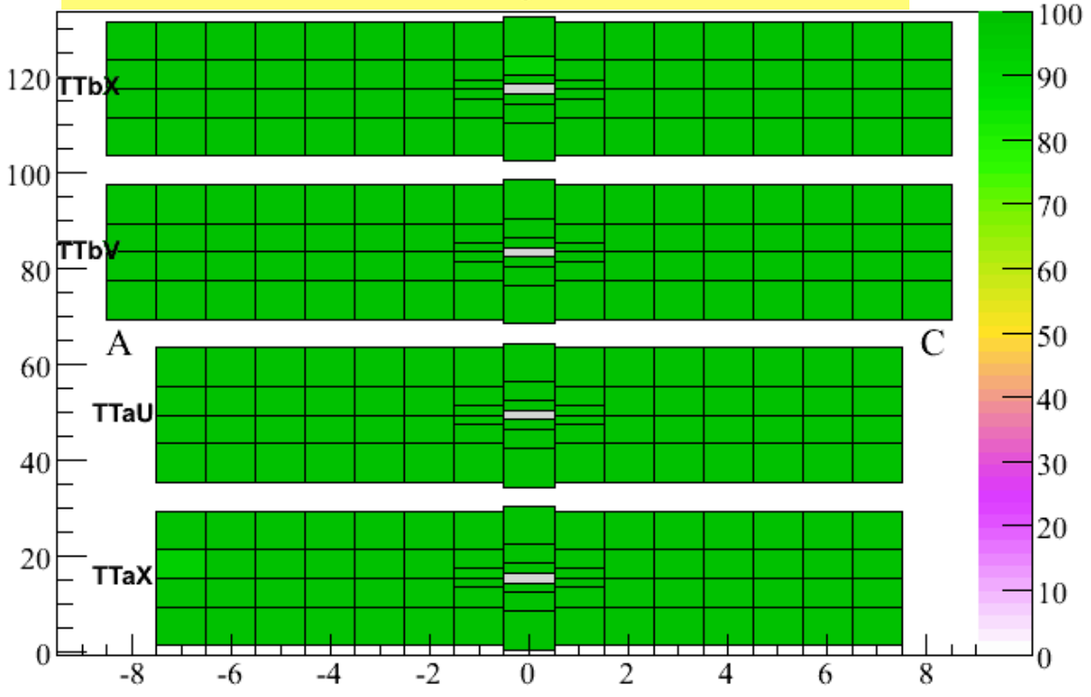
- 3 cosmics through IT in O(10^6) triggers
- Use SPS injection tests instead
- SPS bunches on beam stopper (TED)
  350 m downstream of LHCb
- 5 TED runs in 2008/2009
- High occupancy: tracking challenge
- Allowed first time/spatial alignment
- Signal over noise studies



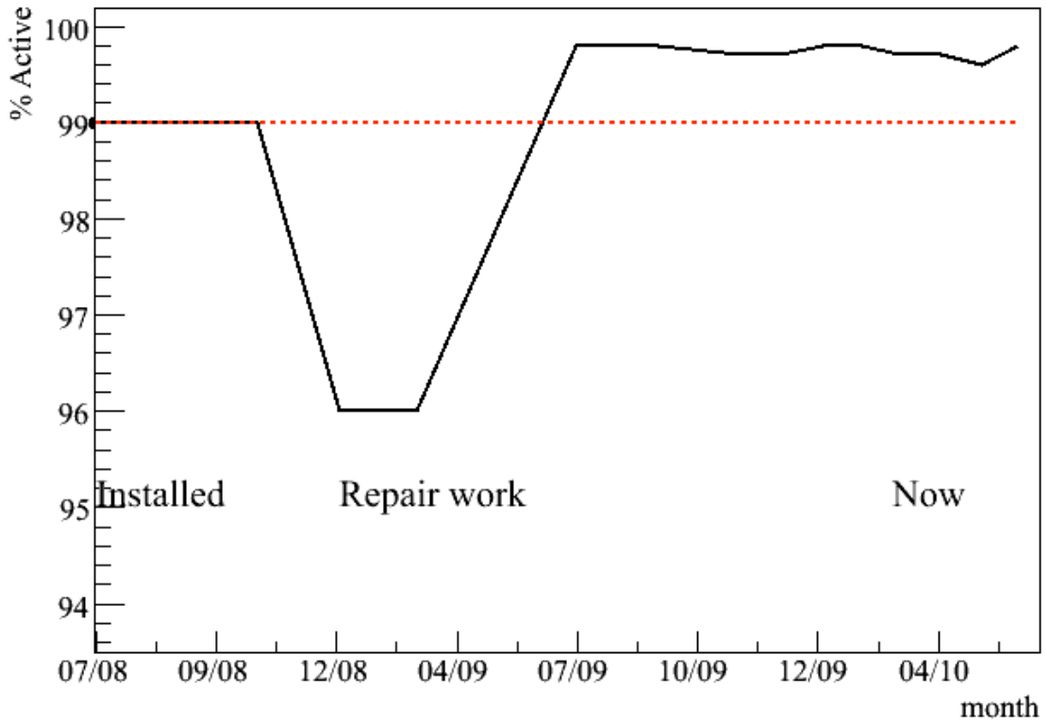
Functionality of detectors

Note: easier access to TT service boxes: easier to fix problems

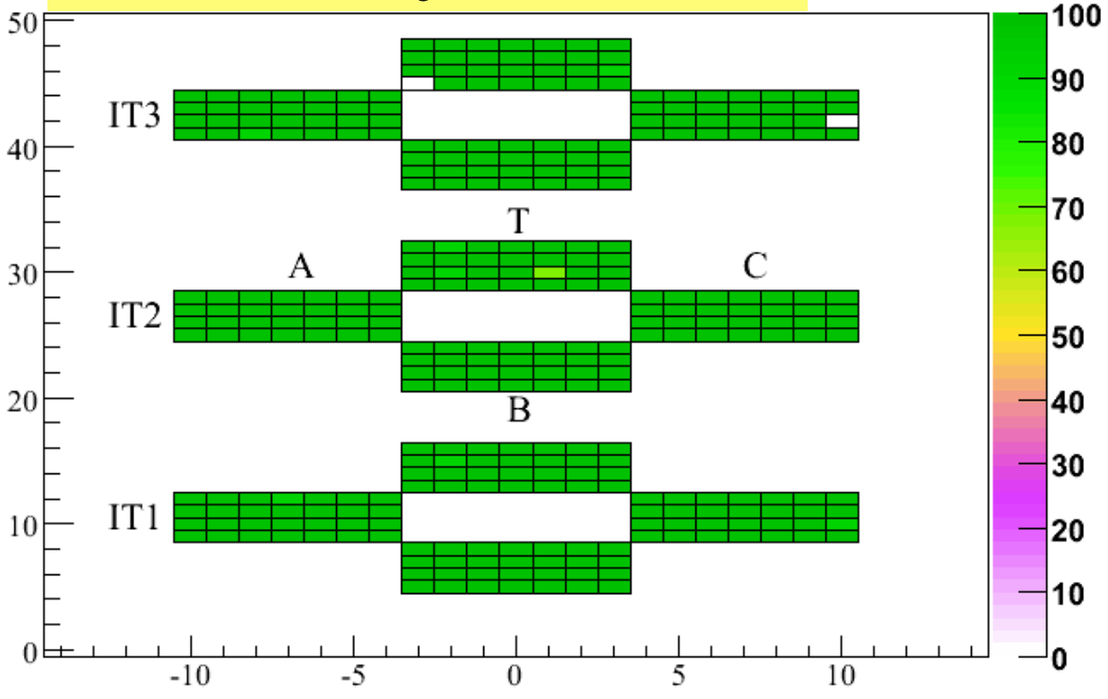
TT 99.8% fully functional



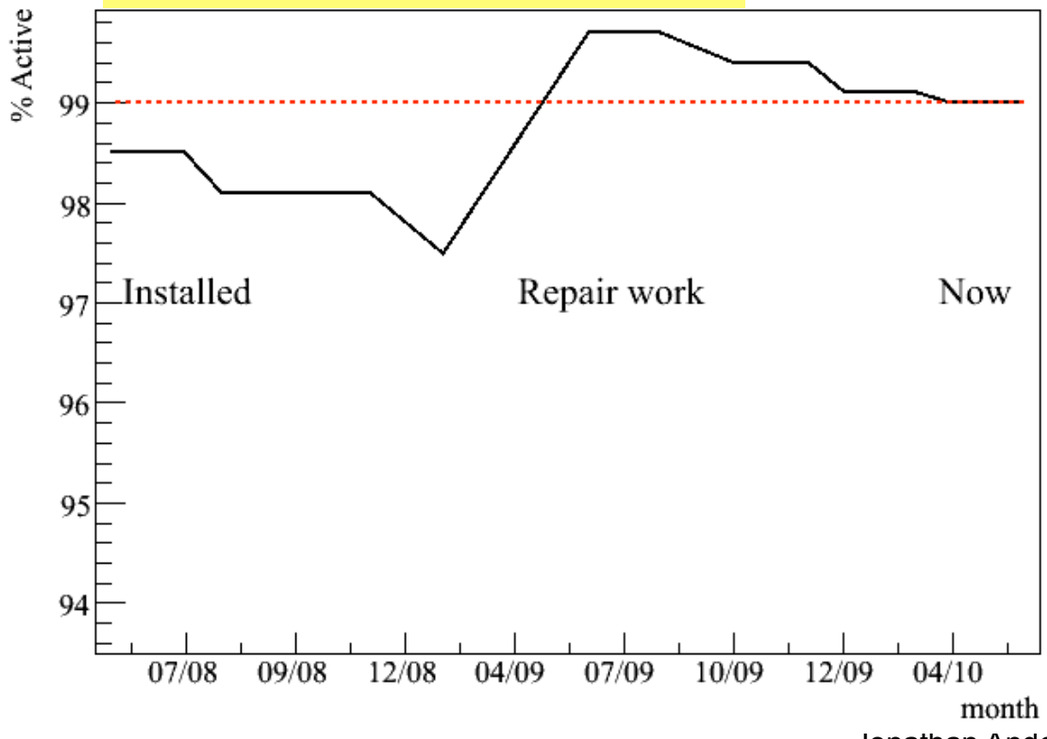
TT status over time



IT 99% fully functional



IT status over time



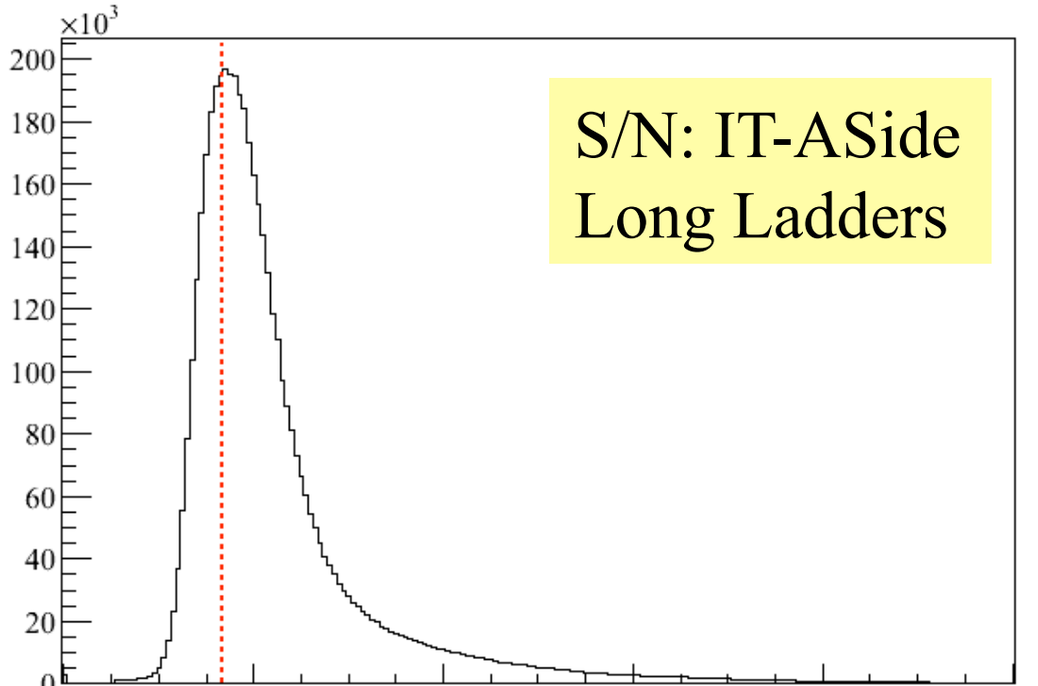
Signal over noise

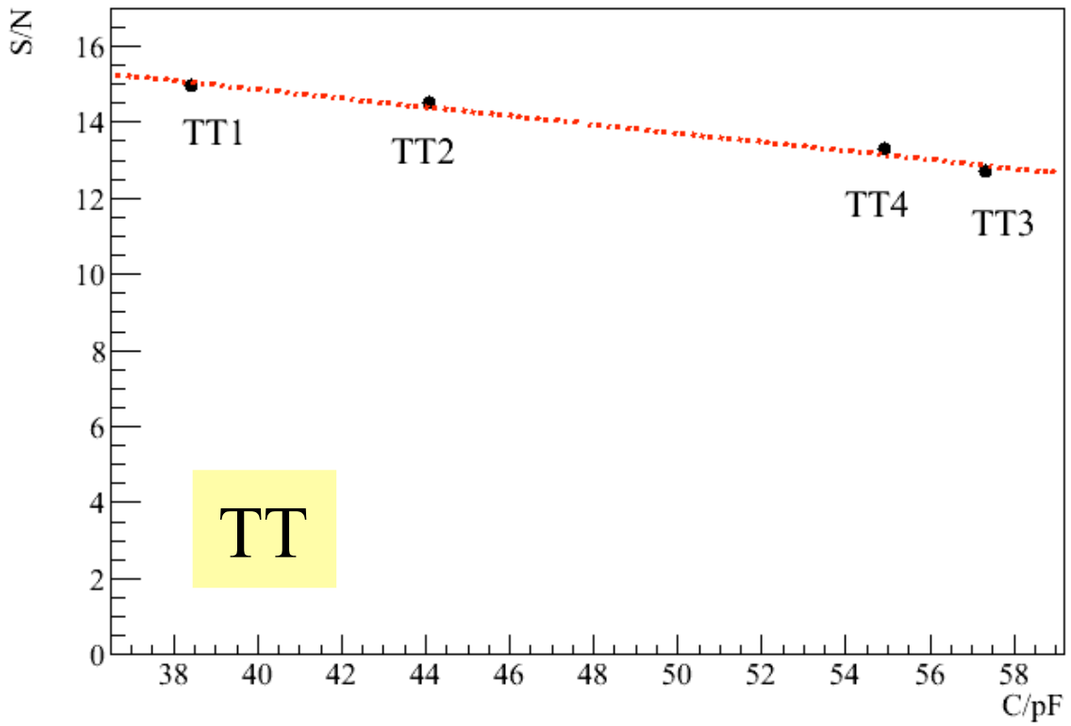
S/N for clusters assigned to tracks with p > 5 GeV

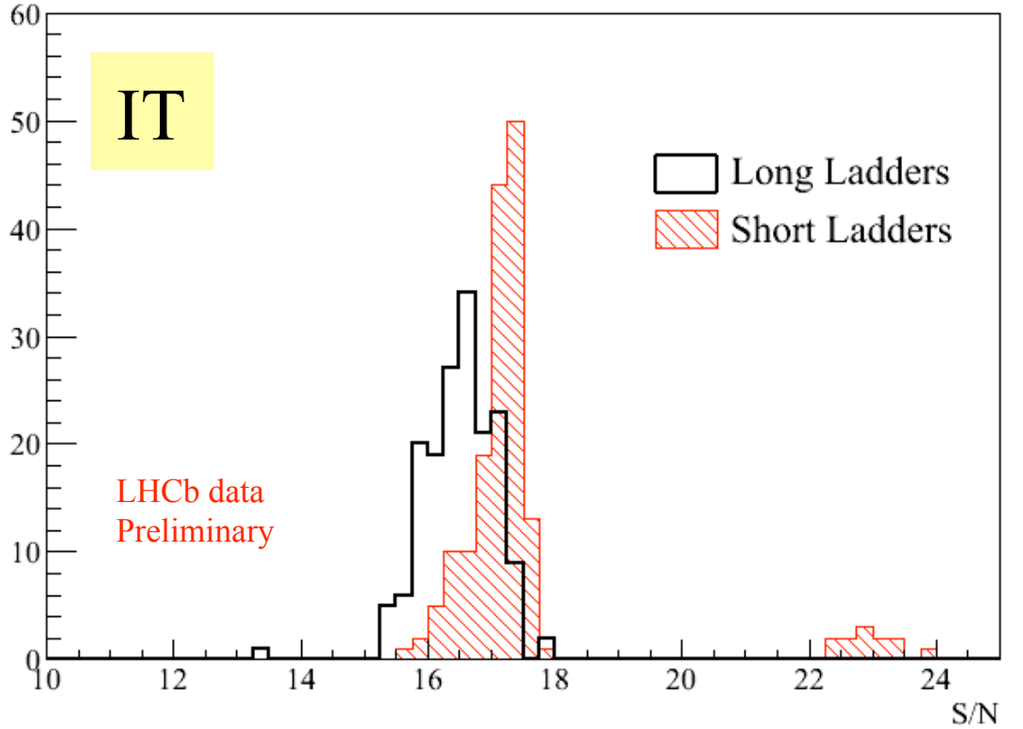
TT: S/N 13 - 15

IT: S/N ~ 16.5 (Long), 17.5 (Short)

Within 10 - 20 % of expectations





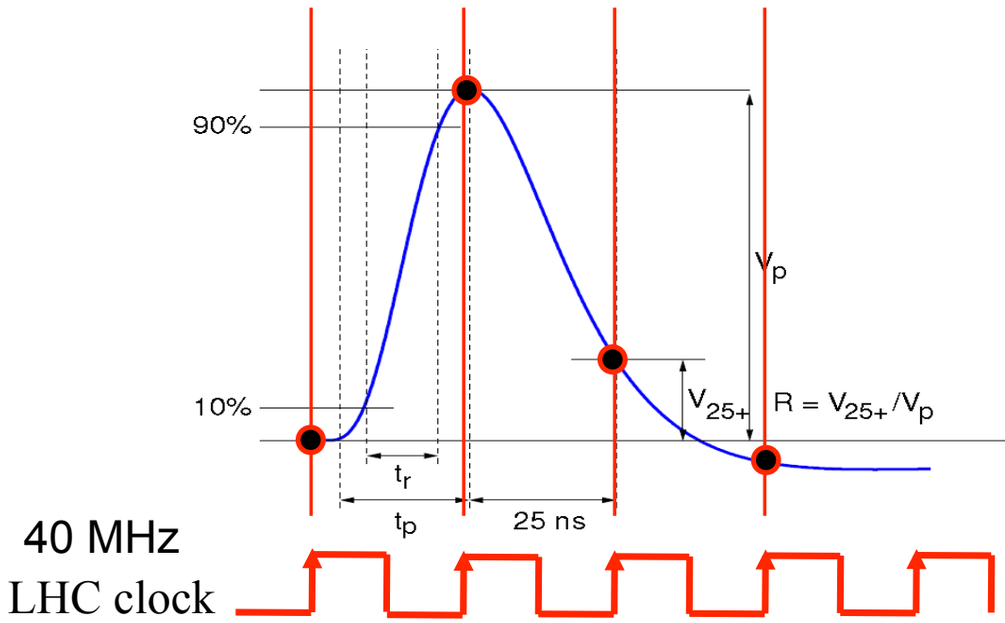


Time alignment procedure

Detectors must be globally aligned in time

- Different cable lengths for different detector parts
- Time of flight different for each station
- Trigger and control signals must be synchronized for the entire LHCb detector
- Achieved by sampling the signal height as a function of sampling time

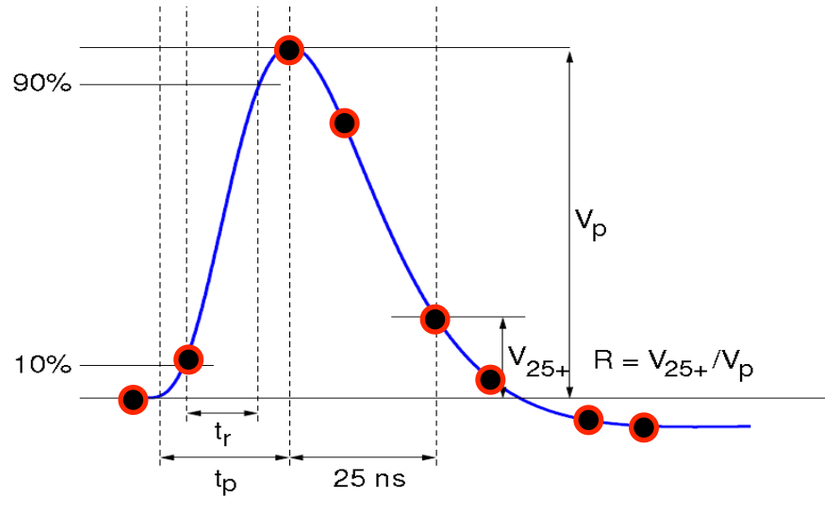
Readout 4 consecutive clock cycles
- Get 4 points on pulse



Procedure:

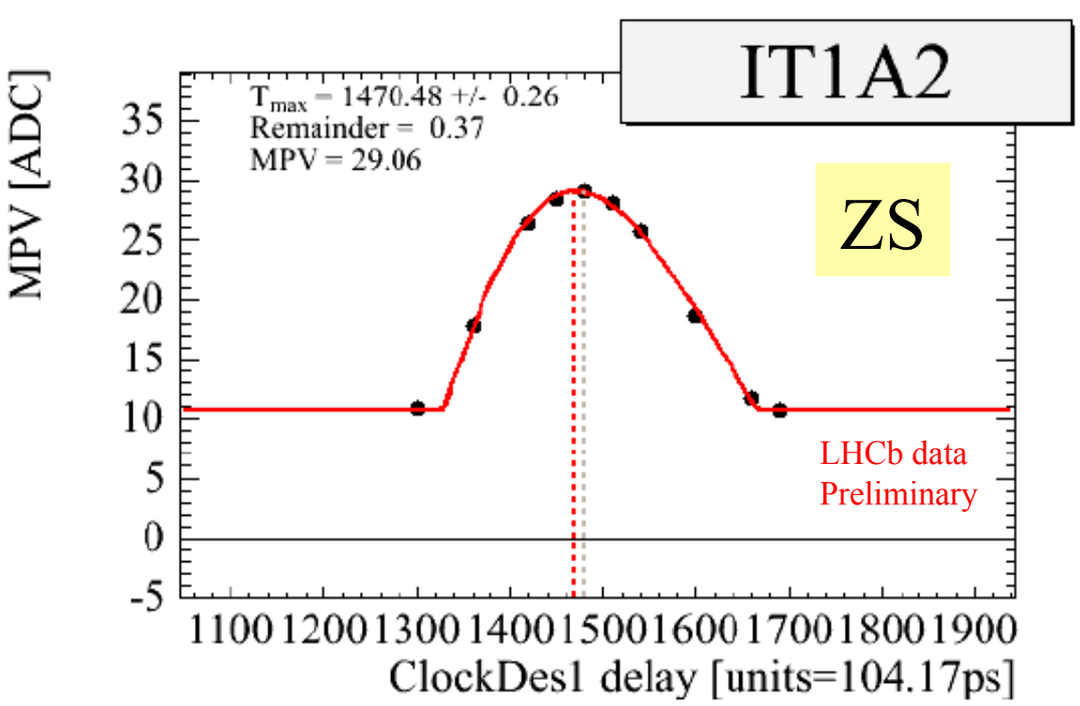
- Dedicated run taken reading out at 25 ns intervals
- Repeat shifting sampling point by -12, -6, 6, 12 ns
- Fit landau to cluster charge distribution for each sample
- Plot MPV vs sample time and fit pulse shape function

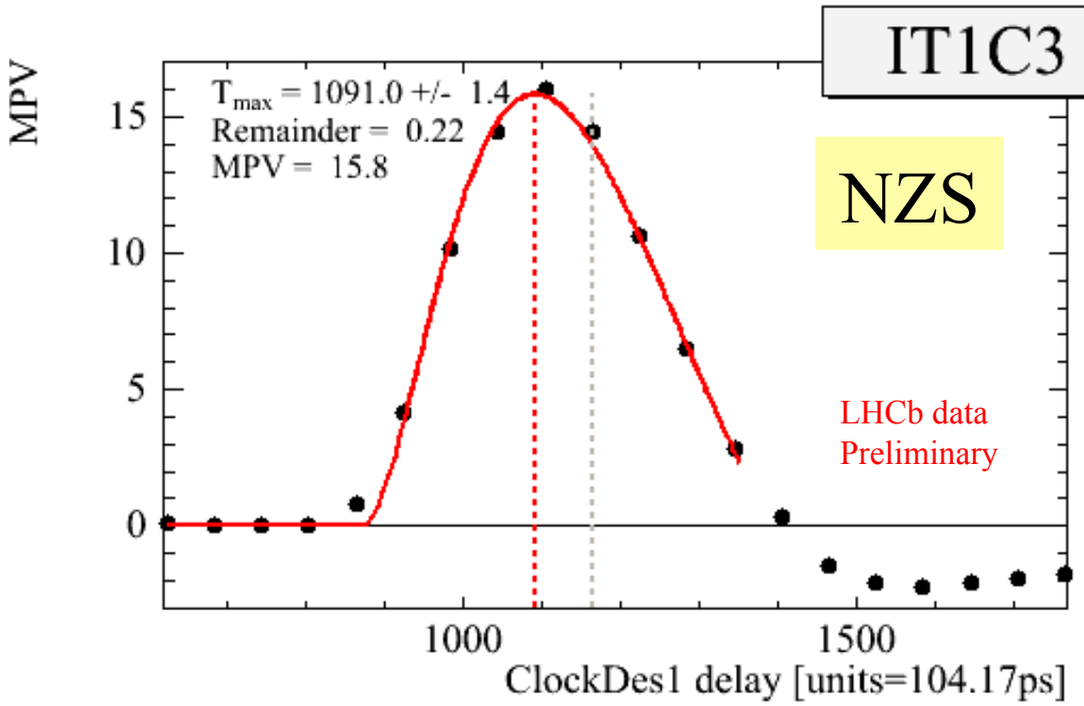
Move sampling points by 6 ns
- Get 4 more points on pulse



Time alignment procedure

- Scans performed for each service box (48 in total)
- Scans use all clusters in event with S/N > 5
- Can be performed with clusters (ZS data) or NZS data (to reconstruct undershoot)



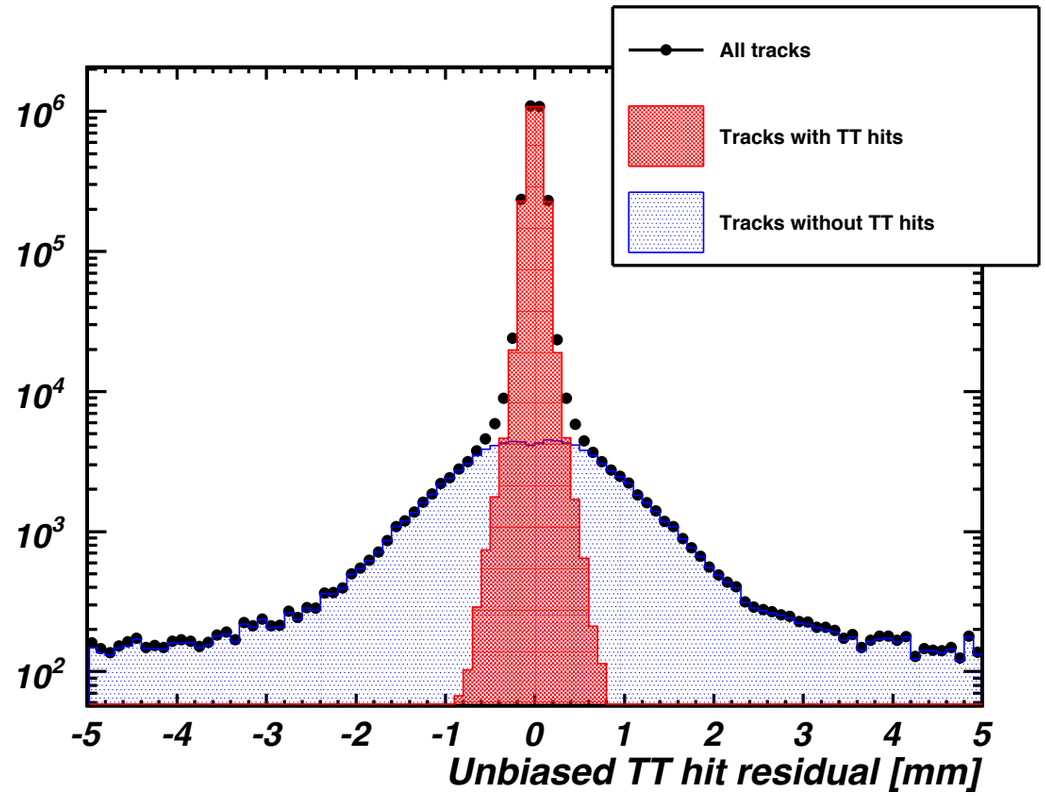


Both IT and TT time aligned with collision data: resolution < 1 ns

TT efficiency

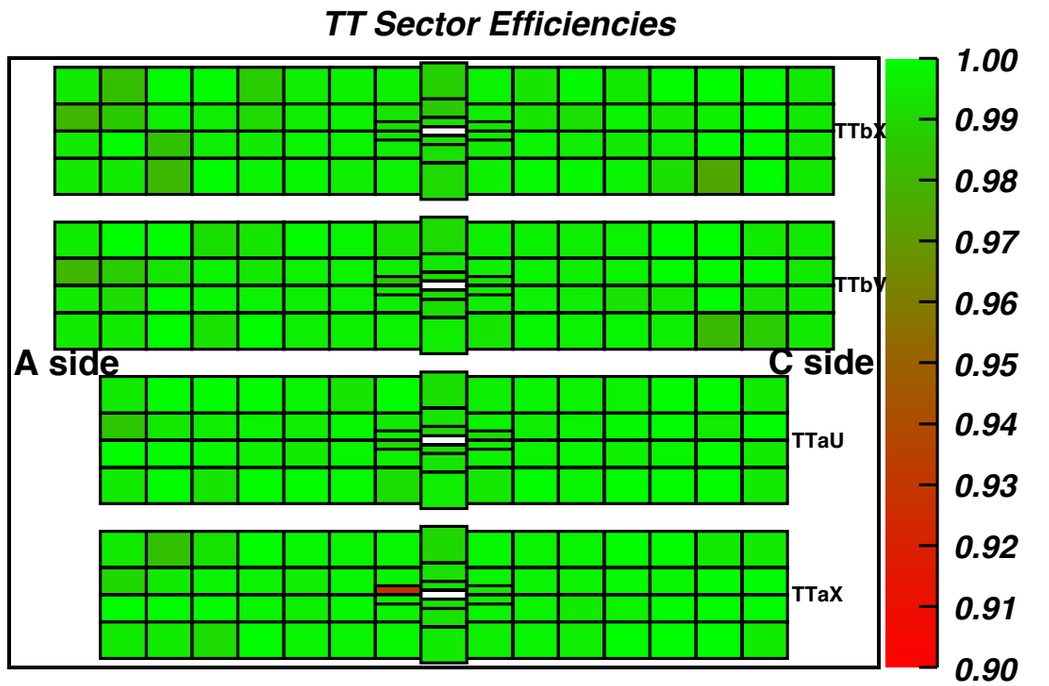
TT Efficiency measured with tracks

- High momentum, P > 10 GeV
- Isolated: little extra activity in 5 mm window
- TT hits are not required by the pattern recognition to be on Velo-T tracks
- 2.5 mm window needed to estimate efficiency



Efficiency measured to be 99.3%

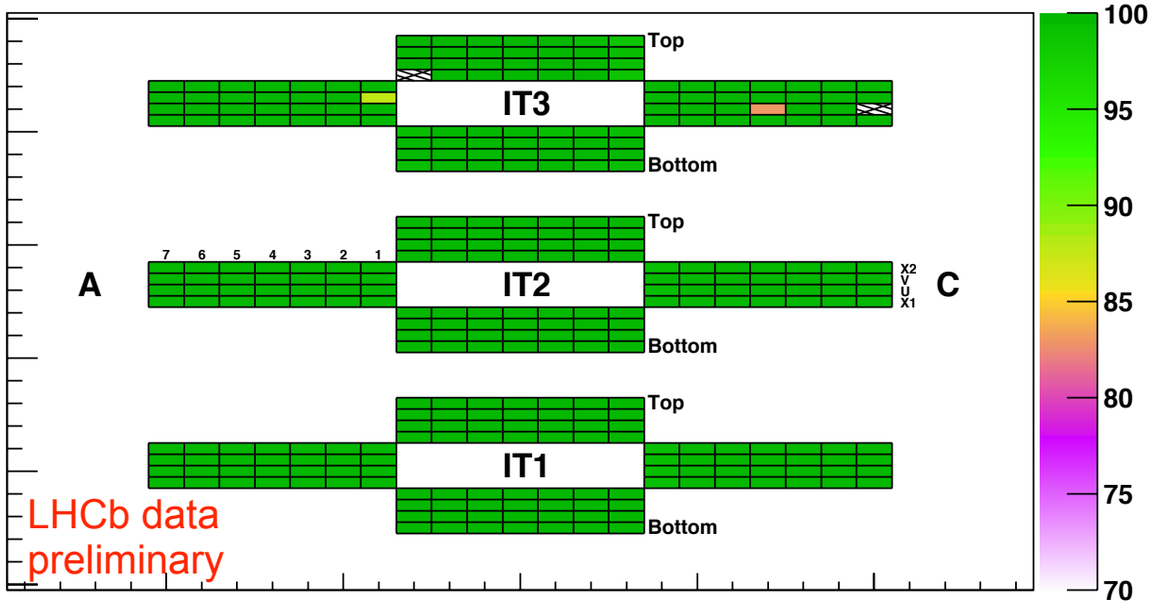
- Clustering threshold, S/N > 5
- Noise cluster rate: 10^{-5}
- 1 low efficiency (~92%) sector: broken bonds



IT efficiency

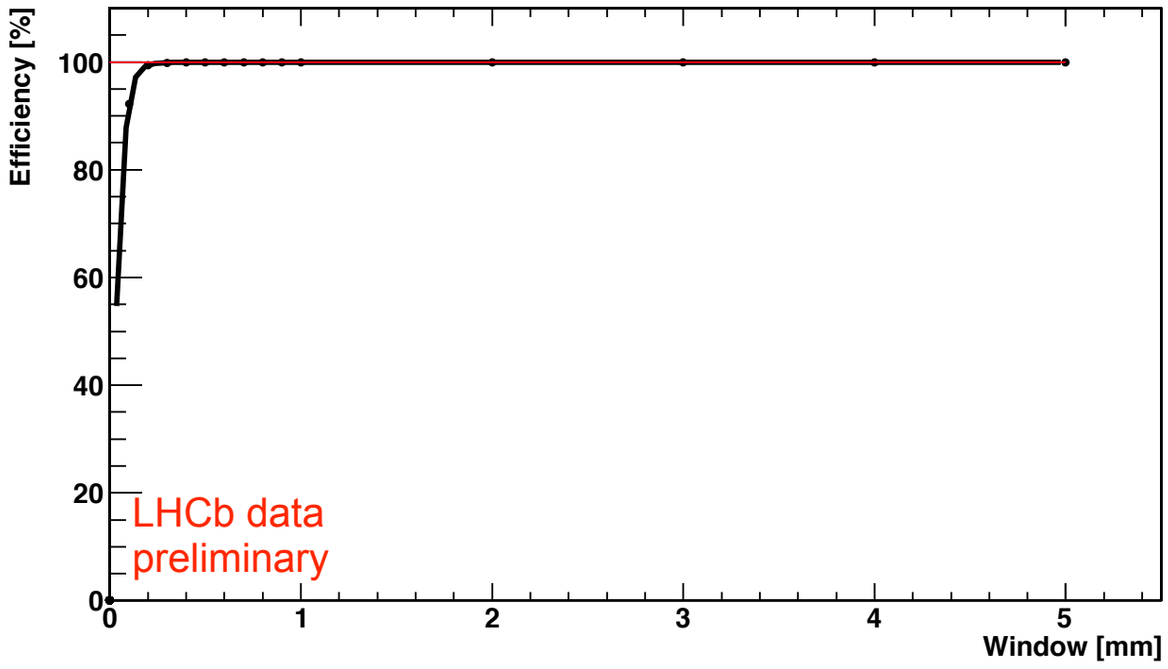
IT Efficiency measured with tracks

- Tracks with hits in VELO
- High momentum, p > 10 GeV
- Isolated: little extra activity in 5 mm window



Detector efficiency ~99.8%

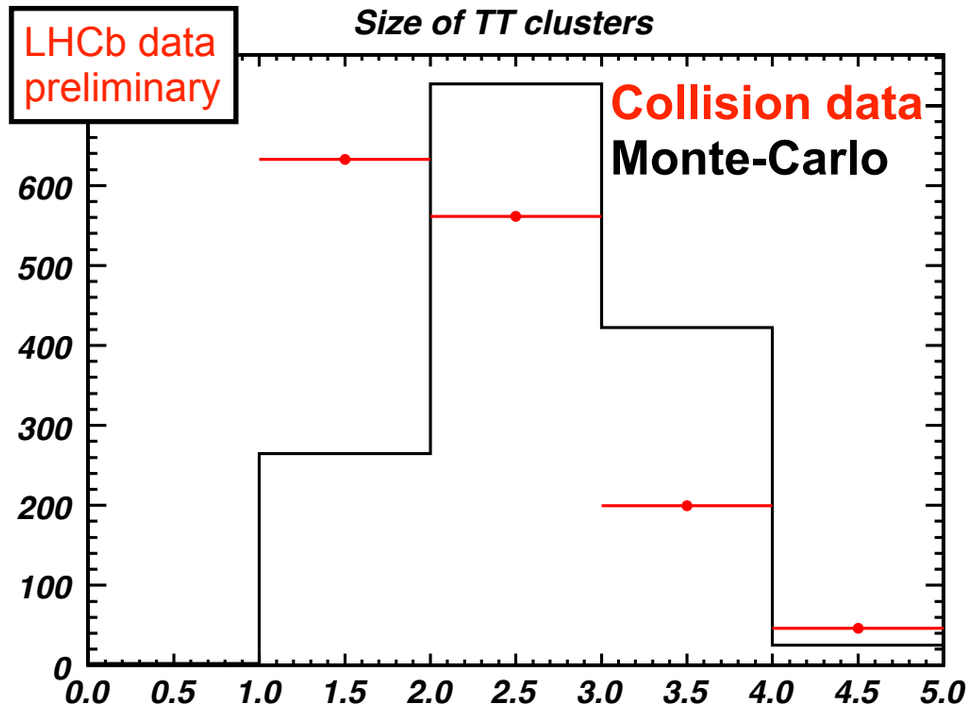
- Clustering threshold, S/N > 5
- Noise cluster rate: 10^{-5}
- Two problem modules
  - one with large common mode
  - one with weak optical link

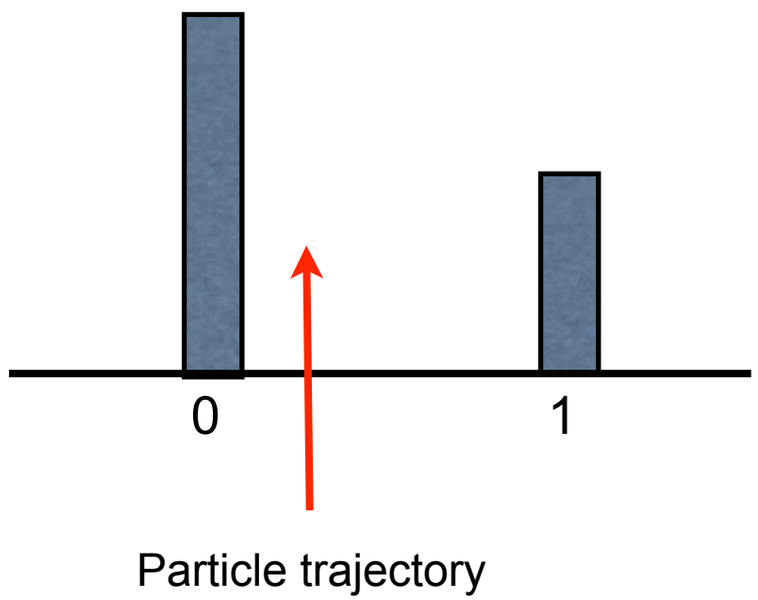


Charge sharing

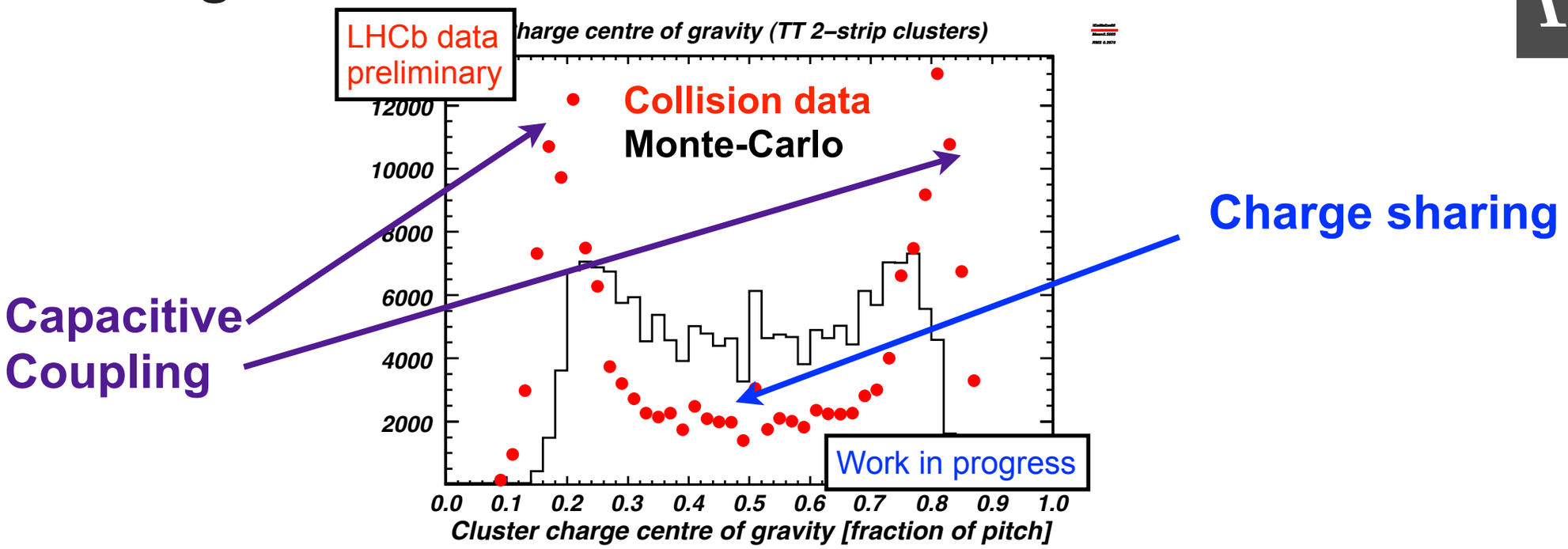
Multi-strip clusters can be reconstructed due to charge sharing between strips

- We see less multi-strip clusters in the data than expected (from MC based on test beam)
- Charge sharing is being investigated using 2-strip clusters
- Plot the fractional position of the track using the particle trajectory vs the centre of gravity of the charges collected by the strips



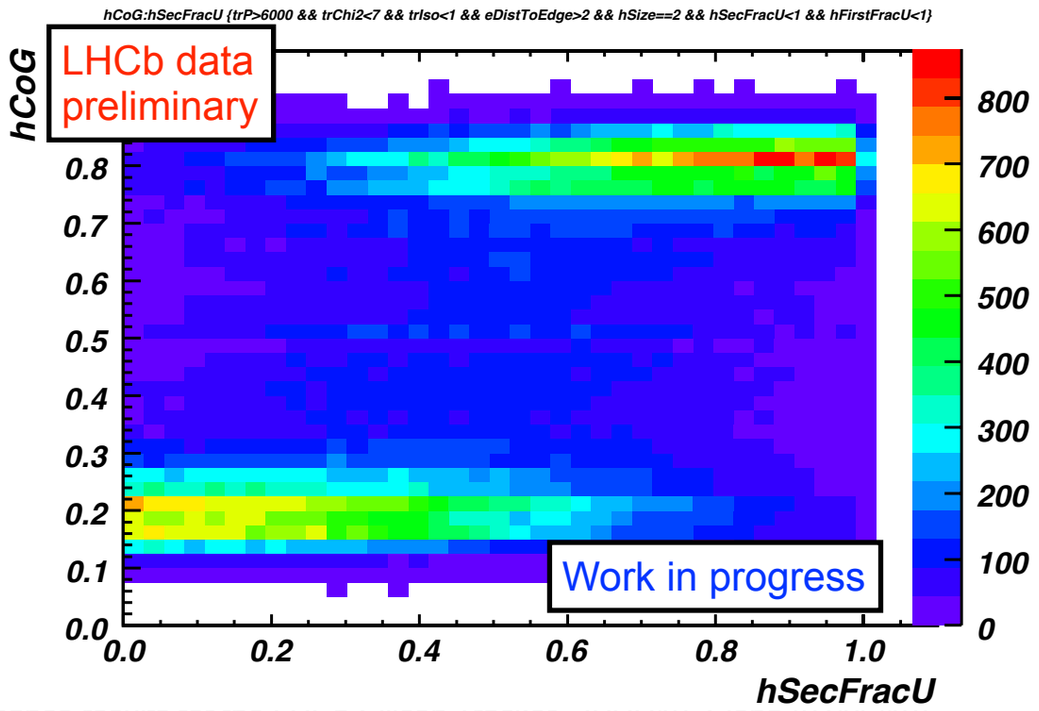


Charge sharing

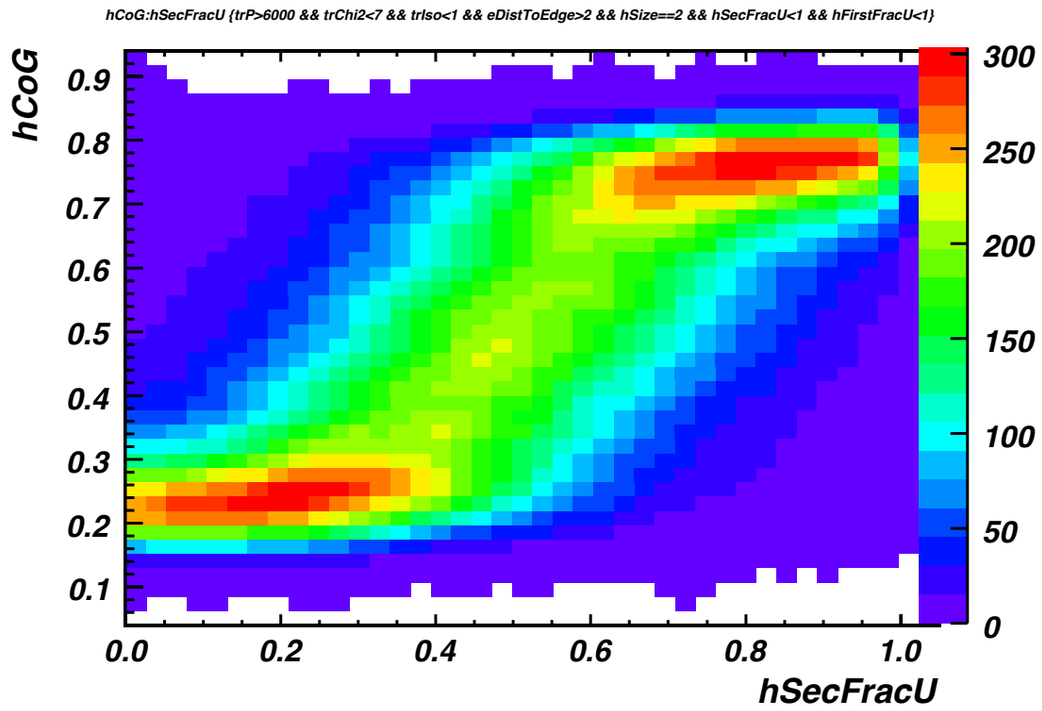


- 2D plot of charge centre of gravity vs position from particle trajectory

Collision



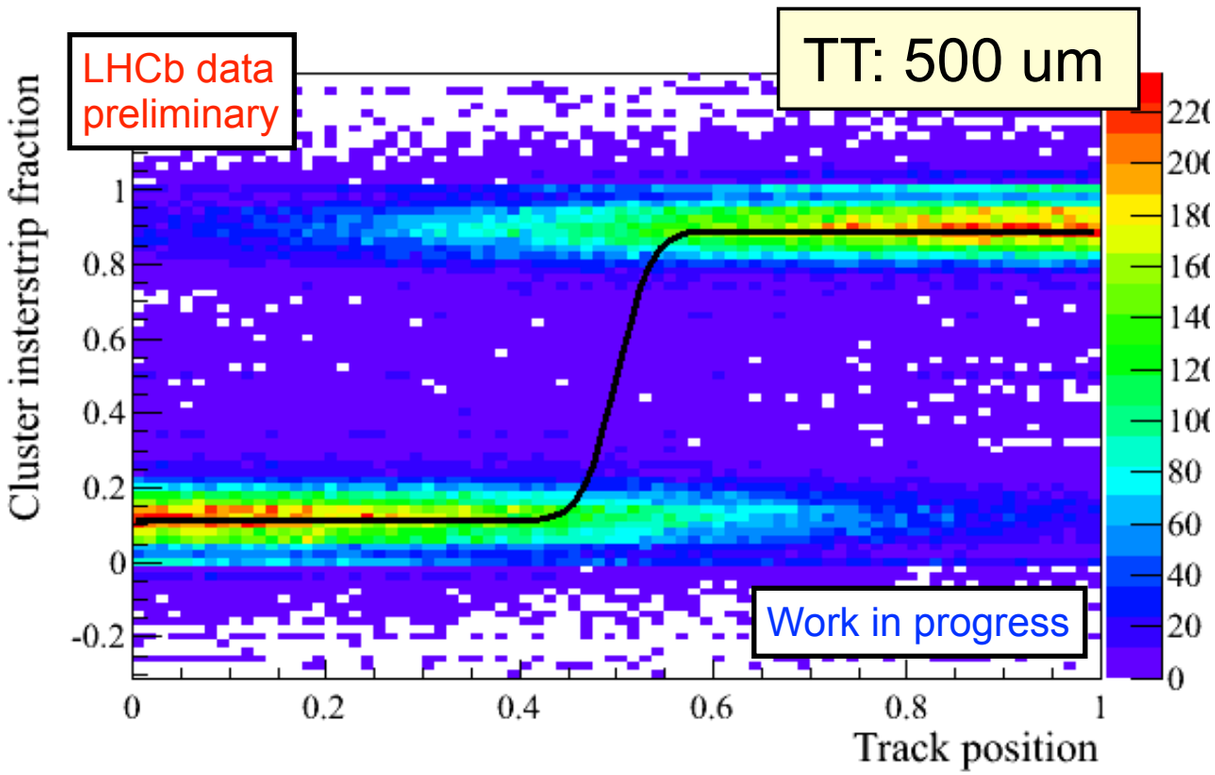
Monte-Carlo

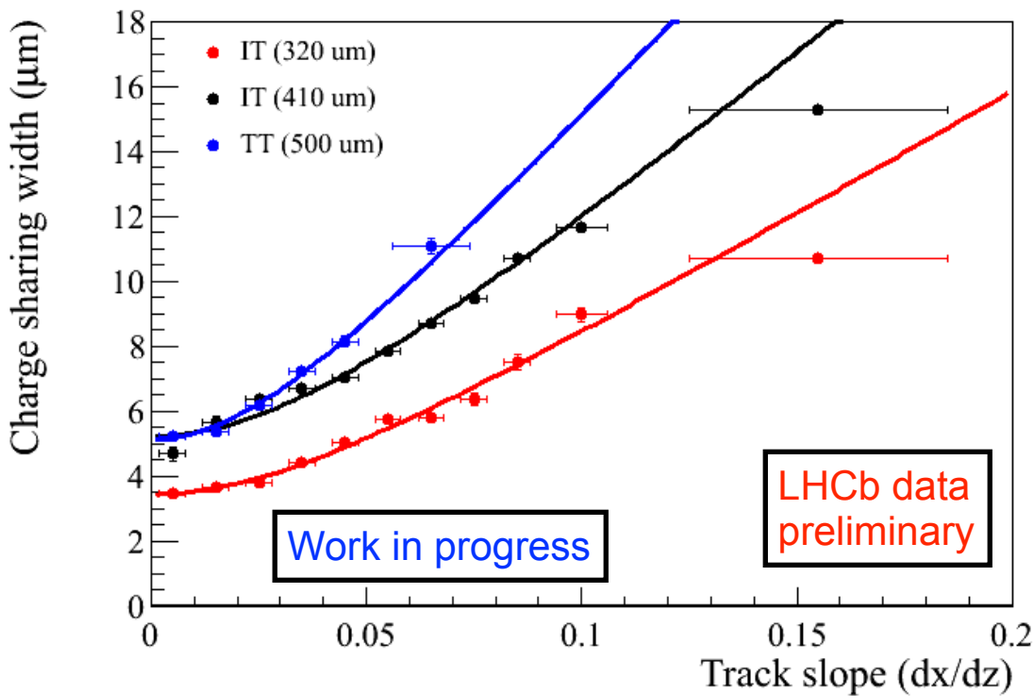


Charge sharing

Extract charge sharing width by fitting 2D distribution with error function convoluted with a gaussian

- In x due to track resolution (mis-alignments)
- In y due to noise
- Can be done as a function of track slope (see bottom right)
- Charge sharing width from data: ~5 μm (20 μm expected from test-beam)
- Still not understood why: work in progress

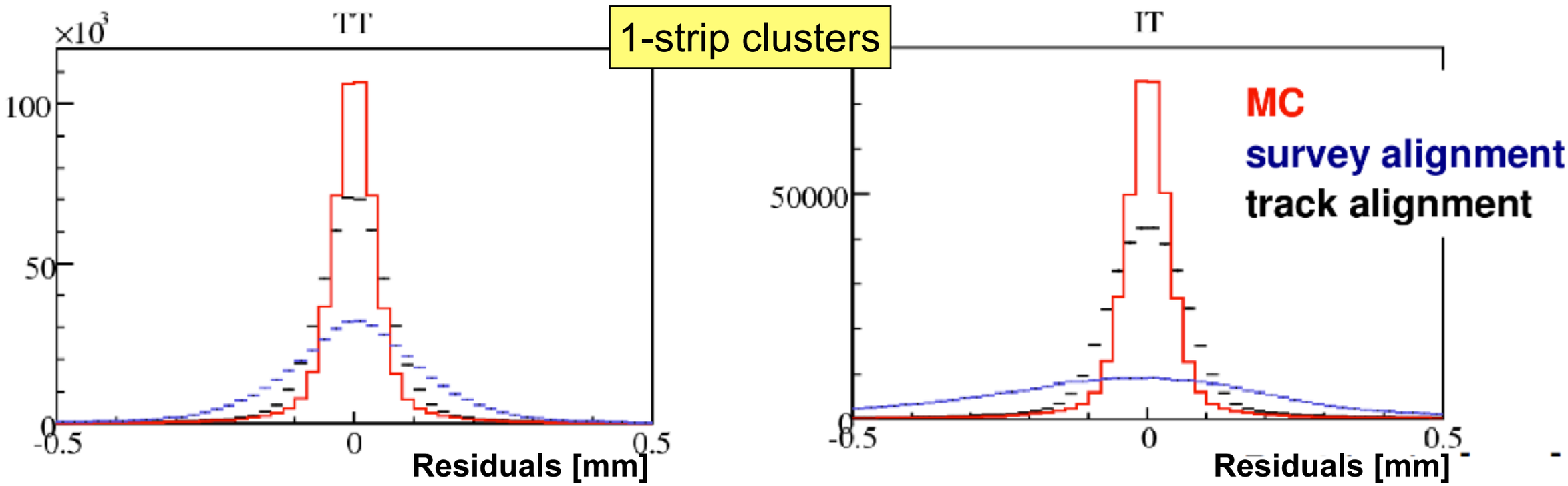




Spatial alignment

Procedure:

- Use tracks that pass through both Velo and T-stations
- Additionally use standalone IT track reconstruction for IT alignment
- Global Chi2 minimisation based on Kalman track fit residuals
  (W. Hulsbergen, NIM A600, 471)



Residual widths for both IT and TT after alignment: **~65 µm**
- ultimately expected to be **50 µm** (work in progress)

Alignment precision

Alignment precision can be assessed by looking at the biases in the residual distributions for all sectors

Current alignment precision errors:

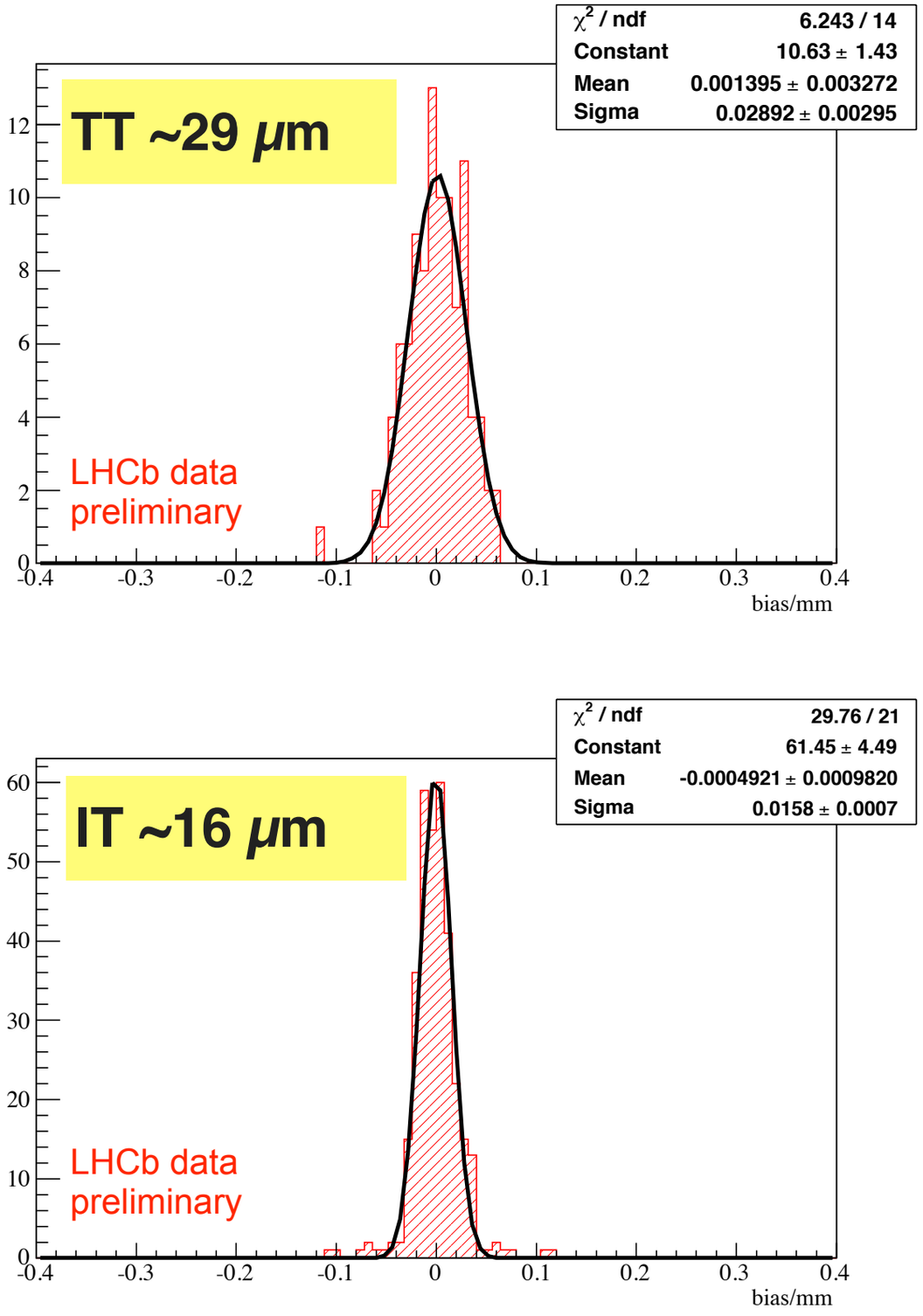
TT: 29 μm

IT: 16 μm

Work in progress:

Target - 10 μm

Ultimately, due to lower than expected charge sharing and remaining mis-alignments, hit resolutions are currently ~30% worse in data than in MC.



Summary

LHCb is taking data!

LHCb Silicon Tracker is installed and running reliably

- Detectors have high functionality (>99%)
- Collision data in 2009/2010 has enabled many performance studies
- Signal over noise measured (TT ~13-15, IT ~16.5-17.5) and in agreement with expectation
- Detector elements have been time aligned with a precision of ~1 ns
- Detector efficiency measured with tracks (TT ~99.3%, IT ~99.8%)
- Charge sharing smaller than expected: investigations ongoing
- Detector elements aligned with a precision of 16 μm (IT) and 29 μm (TT)
  - work progressing